Empirical validation of a method for estimation of susceptibility-by-movement warps directly from the time series.

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Movement-by-susceptibility interaction is a major source of residual movement related variance. This can be remedied by explicit measurement of the field at each time-point or by directly estimating the rate of change of the field with respect to subject movement. In this paper we present an empirical validation of the latter approach. Rate-of-change maps of measured field maps were compared to their estimated counterparts. We found that this method reduced movement-related variance equally well as measured field maps.

INTRODUCTION

Considerable movement-related variance in fMRI time series is a frequent finding even after realignment. This is likely to have several causes: imperfect resampling, intra-volume movements and susceptibility-by-movement interactions. The latter effect is caused by the susceptibility induced spatial distortions being different for different subject orientations [1]. This is particularly a problem in the presence of task-correlated movements where it will cause false positives.

This can be remedied by measuring a field map at each time point and based on that correcting for distortions [2] prior to realignment. Alternatively, one can use the observed variance in the time series to estimate how the field changes with subject movement [3]. The estimation approach does not require any additional measurements and will therefore not affect repetition time of the functional measurement. In this work, we attempt to validate this approach by a direct comparison to measured fields.

METHODS

Data was collected on a 2T Siemens Vision scanner using a dual-echo GE EPI sequence. Each slice was acquired twice in succession with two different echo times. A number of sessions were performed where subjects were instructed to perform voluntary movements according to a predefined sequence. Sessions were: i) resting state, ii) epoch-related visual task or iii) epoch-related motor task.

The phase evolution was assessed from the subtraction of phase images from the two echo times. Phase unwrapping was performed using a watershed algorithm starting from a centrally placed seed visiting gradually noisier areas as the water level rises. A noise-weighted least squares fit of a set of smooth spatial basis functions was performed on the unwrapped phase maps, yielding a smooth approximation. Finally the phase maps were converted to pixel-shift maps and inverted to yield maps in undistorted space. These maps were used to unwarp the modulus images prior to realignment. Maps of the derivative of the field with respect to movement were calculated by linear regression of the realigned field maps onto the estimated movement parameters.

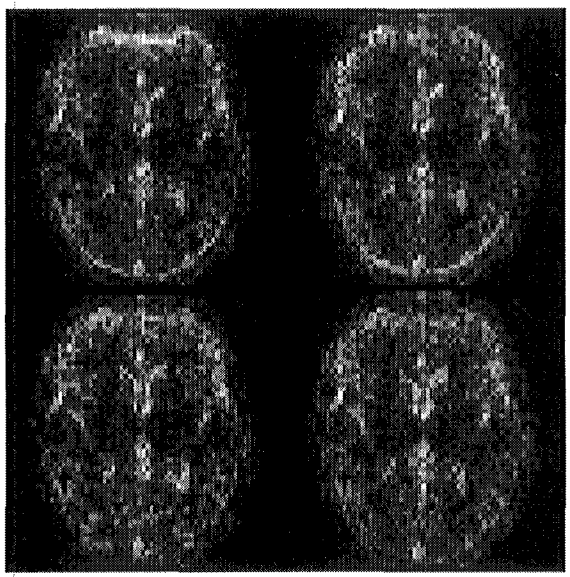
In addition, unprocessed modulus images were subject to realignment and direct estimation of the derivative maps according to a previously described method [3]. The images were differentially unwarped based on linear combinations of the derivative fields.

Variance maps of the time series were used to assess the variance reduction offered by measured and estimated field maps compared to plain realignment. The estimated derivative fields were compared directly to those calculated from the measured phase maps. SPM{t} maps were created for the non-resting state sessions. This was done for realigned data, realigned data including movement parameters in the design, and for unwarped data using estimated or measured field maps.

RESULTS

Both unwarping methods significantly reduced variance in areas known to be affected by susceptibility artefacts. The variance reduction was of a similar magnitude with no one method showing a clear advantage over the other. Variance ratio images (F-maps) between unwarped and realigned data show that variance is affected only in expected areas.

Direct comparison of derivative maps demonstrates a reasonable likeness. The estimated maps show large values (~0.1-0.2 voxels per degree subject rotation) in the same areas as those based on measured maps. In addition, the estimated maps contain a component that compensates for the biased movement parameters resulting from the differential distortions. The estimation method has a tendency to find "unnecessary" warps in areas of the image with no sharp edges. We hope to remedy this by introducing a prior on the derivative fields.



UL: Variance of realigned time series. Note rim of high variance in the vicinity of the sinuses. UR: Variance after unwarping based on measured field maps resliced based on realignment of unwarped data. Note that variance due to biased motion estimates remains along posterior edge. LL: Variance of time series unwarped with measured field maps. LR: Variance of time series unwarped with estimated field maps.

Estimated (left) and measured (right) map of the rate of change of distortion with respect to rotation of the head around the x-axis (pitch). The images are scaled to a range of –0.15 to 0.15 voxels per degree rotation.

REFERENCES

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